MODIS
Ocean Primary Productivity
Data Quality Summary

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Investigation:	MODIS
Data Product:	Ocean Primary Productivity
Data Set:	Terra
Data Set Version:	Collection 4 version 4.2 reprocessed
Dates:	Launch through March 2002
Status:	Terra Collection 4 Validated October 31, 2000 through March 19, 2002 Provisional at all other times Aqua Collection 3 – Provisional Nov 29, 2002 - present

Nature of the Product

Ocean net primary production (*ONPP*) is defined as the rate of inorganic carbon uptake into the ocean biosphere, minus respiration. Biological processes, chiefly photosynthesis, can remove carbon from the dissolved inorganic ocean reservoir, providing an important potential sink for atmospheric carbon. This carbon flux into the ocean biosphere constitutes the base of the pelagic marine food web, directly affecting fishery productivity (Behrenfeld et al., 2002). As part of the Earth Observing System (EOS) science activities at Goddard Space Flight Center (GSFC), the National Aeronautics and Space Administration (NASA) is applying models to remote sensing data from the Moderate Resolution Imaging Spectroradiometer (MODIS), aboard the Terra and the Aqua spacecraft, to compute two indices of *ONPP.*

To quantify this carbon flux, two models from the literature are used to calculate indices of ocean primary production, denoted *P1* and *P2*. The *P1* index is calculated using the Vertically Generalised Productivity Model (VGPM) (Behrenfeld and Falkowski 1997), which estimates daily production over the euphotic zone, and the *P2* index is given by a mixed-layer depth production model (Howard, Yoder, and Ryan). The primary differences between these algorithms are their calculation of the photosynthetic yield efficiency and the depth of integration over the water column. These indices are recorded in the ONPP data products as weekly (eight-day) averaged rates of production in units of grams of carbon per square meter per year.

The key model input data for the ONPP models are 8 day (weekly) composite averages of the MODIS semi-analytic chlorophyll product (Chlor_a_3) and the MODIS daytime sea surface temperature (D1) in Integerized Sinusoidal Equal Area Grid (ISEAG) projection, at 4.63 km resolution. Both models also use photosynthetically available radiation (PAR) is derived from surface incident short-wave surface flux estimates provided by NASA's Data Assimilation Office (DAO). The PAR, which is provided in one degree, unprojected global observations for every 3 hours, is averaged over the MODIS weekly period of eight days. For the P2 model only, daily synoptic mixed-layer depth (MLD) at one degree resolution is provided by the U.S. Navy's Fleet Numeric Meteorology and Oceanography Center, and also averaged to the MODIS weekly period.

The MODIS ONPP global data products are created every eight days, at resolutions of 4.63 km in the Integerised Sinusoidal Equal Area Grid (ISEAG) projection, and are available to the public through the GSFC Distributive Active Archive Centre (GDAAC). In addition, cylindrical, equidistant projection maps of all model input data and results are available at 4.88 km, 39 km, and one degree linear lat-long resolutions. The 39 km resolution map images are also accessible through the MODIS Ocean Quality Assurance Browse Imagery browse tool (MQABI) at http://mqabi.gsfc.nasa.gov . Means for weekly periods, basic statistics, and input parameters are available as mapped images and binary files at this web site. In addition, access and visualisation capability of these products is available at the Ocean Primary Productivity Science Computing Facility (OPP/SCF) website at http://opp.gsfc.nasa.gov . The availability of these various products will open new opportunities to deepen our understanding the biological health of our oceans and the role of the ocean biosphere in the carbon cycle.

Product Accuracy

The ONPP product accuracy is strongly dependent upon the accuracy of input products Chlorophyll_a_3, and Daytime Thermal SST, and are valid only if input chlorophyll a-3 and SST are of valid status. Presently this occurs only for Terra, during the period October 31, 2000 thru March 19, 2002. The chlorophyll input fields have been compared with in-situ data at the daily level for quality 0 and 1 (see below) during that period and show an RMS difference of 0.28 (Gregg and Casey, 2003).

$$RMS = \frac{\sqrt{(\log(Chl_{sat} / Chl_{insitu}))^2}}{n}$$

SST values have been compared with *in-situ* skin and bulk measurements and show a bias of 0.16 or -0.14 K, respectively, and a standard deviation of 0.42 K or 0.51K, respectively (Brown et al. 2002). We have compared DAO PAR fields with SeaWiFS

PAR (Frouin et al., 2001), and found an r2 of 0.97 and a slope of 1.09 (Figure 1). We have not performed analyses of MLD.

The initial validation of the ONPP products was primarily based on model verification and validation. That is, if the models are implemented correctly, then it is reasonable to assume that the model validation efforts done to date reflect the ONPP product quality. This is, of course, provided that data for the most influential model input parameters used to produce the ONPP products are comparable in quality to those used in the validation work.

Both models were rigorously tested against input data and results provided by the original developers. Therefore, there is a high degree of confidence that the algorithms were implemented per design. This is also evident when comparing results with the same or similar models in the Primary Productivity Algorithm Round Robins (PPARR) 2 and 3. The models for P1 and P2 were further evaluated, along with others of similar class (Campbell et al. 2002). Since the MODIS input products are of validated quality, we consider the ONPP product have valid outputs according to the model sensitivities.

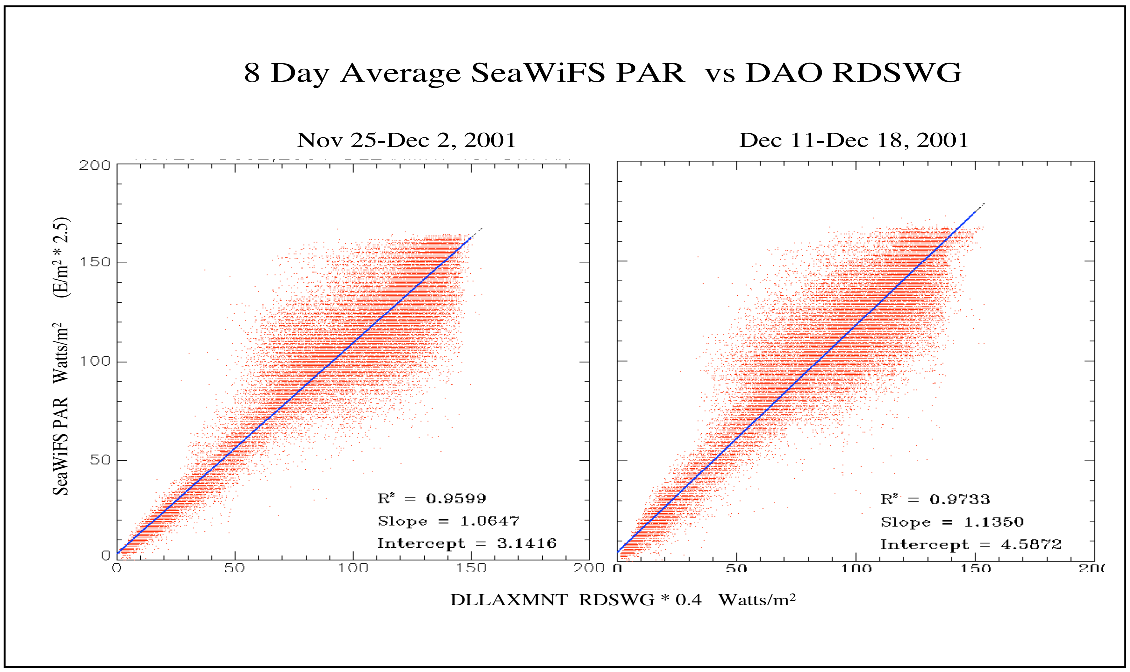

Figure 1 Comparisons of SeaWiFS PAR and DAO RDSWG

In PPARR 2, ONPP algorithms were generally found to predict ^{14}C incubation measurements of C uptake within a factor of two. Given the current assessments, the MODIS data is of comparable, if not better quality, than data used in that study. A similar range of uncertainty can be seen in match-ups of 4.63 km ISEAG gridcells of the ONPP binned product with in-situ data from the BATS, HOT and CalCOFI cruises (see Figure 2). What should be noted here however, is that the uncertainty range may not exclude a spatial correlation in error or other trends (e.g., overestimates of gyres).

It also should be noted that both match-up studies did not account for the spatial scale difference between sample bottles and satellite data pixels, or procedural differences in collecting the data at sea (Campbell et al, 2003). Moreover, the match-ups shown in Figure 2 have a temporal scale difference, since the ONPP product contain estimated eight-day averages, and each *in situ* observations estimate the production for one day. These effects could contribute strongly to the dispersion, and the ONPP data could conceivably predict courser scale aggregates with less uncertainty. However, the overall course scale biases, evident in Figure 2, may represent the true nature of the ONPP data uncertainty, which still remains within the range of a factor of two. Thus a user of the data product must be understand that the uncertainty range thus stated does not imply errors without trend or bias.

Mathematical analysis shows that the most important input parameter influencing ONPP quality is the MODIS semi-analytic chlorophyll (chlor_a_3) (Turpie and Esaias, 2003). Of lesser importance is the daytime 11μm sea surface temperature (SST), followed by photosynthetically available radiation (PAR). The mixed-layer depth (MLD) used exclusively by the P2 model, also has a low rank of influence of ONPP quality over most of the ocean area. As indicated by respective data quality summaries, the MODIS input products were shown to have uncertainties comparable or better than those used by validation work mentioned above. Although uncertainties for the ancillary data inputs, PAR and MLD, are not well documented, it is reasonable to assume that their contribution to the overall uncertainty is small for most of the ocean. However, it should also be noted that in regions of high chlorophyll concentration (e.g., coastal regions), the models become less responsive to fluctuations in chlorophyll and thus perturbations in the other input parameters can become significant (Turpie and Esaias, 2003).

Analysis of model response to various input chlorophyll models (Esaias et al, 2003) suggests considerable model robustness at global scales with respect to uncertainty in input chlorophyll. The model predictions of global annual carbon uptake agree within 10% when the three different MODIS chlorophyll products and the Repro 4 SeaWiFS chlorophyll product are used as input. Moreover, inspection of model mathematics reveal that a relative error in chlorophyll yields smaller relative uncertainty in the ONPP product, thus afford some robustness to the ONPP product (Turpie and Esaias, 2003). Thus, minor variation in input chlorophyll quality will not be amplified in the change in quality in the ONPP data product.

Caution When Using Data

It is recommended that only data values with quality level 0 and 1 (*best* and *good*, respectively) be used. ONPP quality level is weighted toward the input chlorophyll product quality. The product quality is most dependent on chlorophyll input, SST quality generally is equal to or better than ocean color on a pixel basis, and quality of MLD and PAR input fields are assigned a default of 0. The ONPP quality level is set to 0 or *best* wherever the chlorophyll quality level is set to 0 and SST is either 0 or 1.

ONPP Quality	Chlor QL	SST QL
0	0	0,1
1	1 (<30m)	0,1
2	1 (>=30m)	0,1
3	2	0,1

Table 2. ONPP Quality Flag definitions

If the chlorophyll quality level is set to 1, then the ONPP quality level is set to 1 over shallow water (z < 30 meters) only and 2 elsewhere. The binning process for chlorophyll is such that shallow waters will always be assigned quality 1 regardless of binning period, whereas the open ocean scan edges assigned a QL of 1 will gradually disappear in larger binning periods as the probability of any quality 0 data increases. In most instances, the shallow water chlorophyll values are quite useful, and represent a significant fraction of the global and regional ONPP. The ONPP quality levels are set to 3 or *bad* for all other chlorophyll quality level settings. Calculations are not performed for chlorophyll QL =3 or SST QL of 2 or 3. PAR and MLD are based on the entire file, and are not factored into the ONPP quality level.

In addition, ONPP values greater than 1000 g C m-2 y-1, should be used with caution. Likewise, model results that used input chlorophyll concentrations > 20 mg m^{-3} or input SST > 28.5 C^{o} should be used with caution. Flags for each of these conditions can be found in the ISEAG projected dataset (known as *binned data*), in the Vdata field L3_WPI_Flags. The bit positions these flags and others are given in Table 2. For PAR and MLD, if all files are present (64/8day period) QL=0 in the binned file (see below). For less than 100% files, Ql=3*(64-N)/64, and QL is 3 if climatology is used.

It should also be advised that uncertainties associated with the data should not be considered spatially (or temporally) independent. That is, errors in pixels or grid cells in close proximity are likely to be correlated. Thus, a particular error within in the uncertainty ranges cited above could pertain to a larger region. The correlation radius of these uncertainties are not well understood. Quantification of such correlations will require more extensive study of the models predictive capabilities and effects on input data accuracy.

Finally, in estimating global or regional OPP using these products, the user is cautioned to be careful of effects that can be caused by missing data or scaling effects. The integral ONPP for regions and global areas are a function of the resolution of the input data. The highest resolution (binned 4.6 km) data sets are least affected by scaling effects but represent the least complete coverage.

Table 2 - WEEKLY BINNED DATA FLAGS (L3 WPI FLAGS)

Position[+]	Size (bits)	Flags Description	Setting Conditions
0- 1	2	P1 Quality Level	*
2	1	RESERVED	
3- 4	2	P2 Quality Level	*
5- 8	4	RESERVED	
9-10	2	Chl Quality Level	*
11	1	RESERVED	
12-13	2	SST Quality Level	*
14	1	RESERVED	
15-16	2	PAR Quality	*
17-18	2	MLD Quality	*
19	1	High Chl Mean	Chl mean > 20 mg m-3
20	1	High Chl Std Dev	Chl std dev > 20 mg m-3
21	1	Low Chl sampling	No. of obs < 8
22	1	High SST Mean	SST mean > 28.5 C
23	1	High SST Std Dev	SST std dev > 10 C
24	1	Low SST sampling	No. of obs < 8
25	1	Zeu cutoff	Euphotic depth > 30m in shallow water
26	1	MLD cutoff	MLD > 30m in shallow water
27	1	High P1	P1 > 1000 g C m-2 yr-1
28	1	High P2	P2 > 1000 g C m-2 yr-1
29	1	Shallow water	set if Z > 30 meters.

+ Position of the least significant bit is 0.
* Quality level values 0-3 denote the following: 0=best, 1=good, 2=fair, 3=bad

Expected Revisions

Missing Data (Hole) Filling
Scale Adjustments
Improved bathymetry, identification of clear shallow regions, setting physical depth integration over shallow regions
Model improvements

Quality Assurance

The ONPP weekly outputs are examined at 36 km resolution, and summary statistics are computed and plotted as time-series which are available on MQABI http://mqabi.gsfc.nasa.gov . The ONPP product will require further monitoring to identify quality anomalies that could affect product quality (e.g., anomalies within an upstream product). Such events are reported at the known problems and comments pages at http://modis-ocean.gsfc.nasa.gov . Evaluation of regional biases is ongoing and is necessary to quantify uncertainties as a function of space and time, or to at least identify any major regional biases or anomalies.

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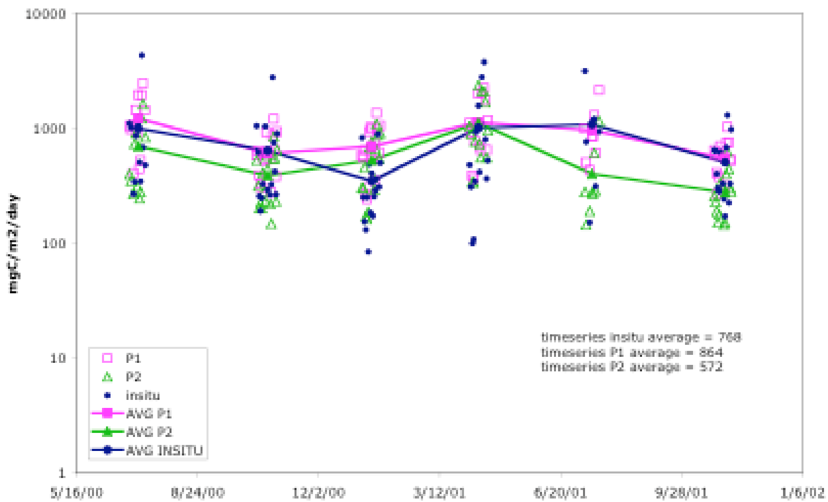

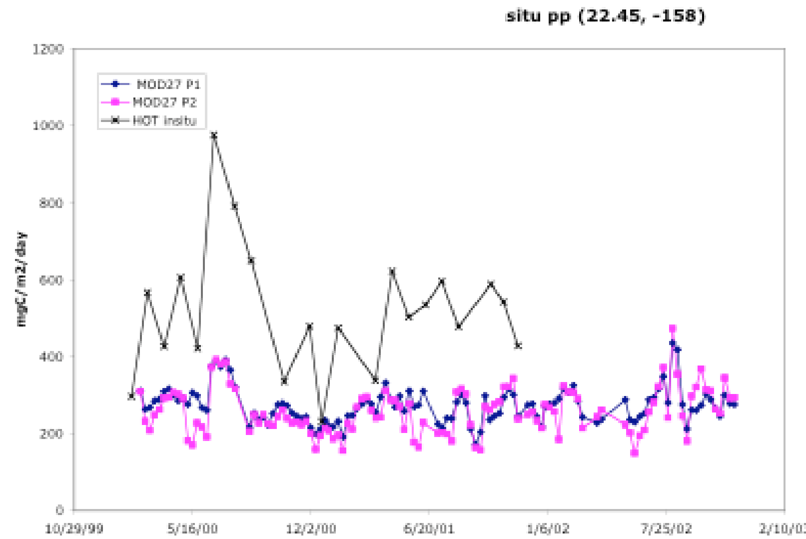

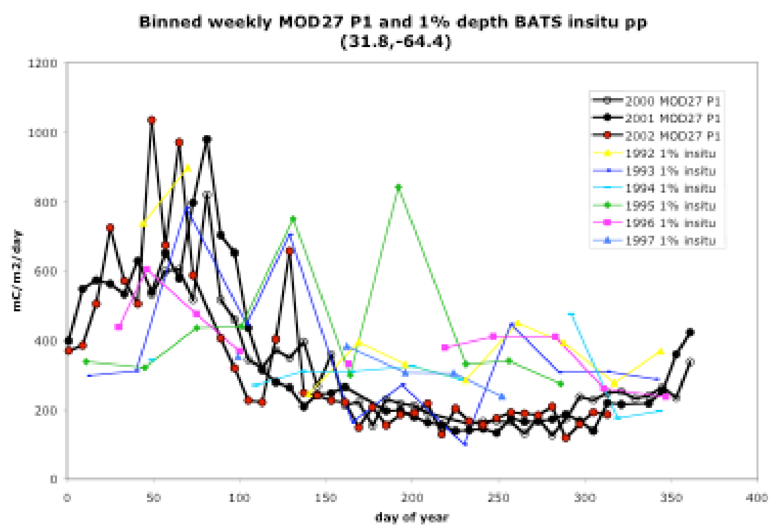

Figure 1 – Match up of MODIS Primary Productivty Data with *in situ* BATS, HOT, and CALCOFI data.